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METEOROLOGY AND THE POSITION OF SCIENCE IN AMERICA.

BY PROFESSOR CLEVELAND ABBE.

A RECENT number of the NORTH AMERICAN REVIEW contains an article, entitled "America's Inferior Position in the Scientific World" that has attracted considerable attention. We notice that the author has said nothing with regard to the very high position that America holds in several branches of science; and, therefore, I may be allowed to say a few words about one of these—namely, meteorology.

Before entering upon that specific subject, however, it may be well to observe that we must avoid confounding two distinct ideas, viz., "America's position in the scientific world" and "the position of science in America." The former is secure, the latter is still unsatisfactory; and it is the latter that we may seek to improve by practical means. It is not denied that America has thus far honored her inventors more than her men of research. In popular esteem the practical is often put higher than the theoretical, because it comes nearer to the popular heart. The investigator is liable to be neglected in comparison with the teacher or the lecturer; and the latter, in turn, are rewarded and supported less liberally than the inventor or manufacturer. Even in Europe the great engineers generally receive more attention than the investigating physicists, although the latter lay the foundation for the work of the former. The same holds true in astronomy, chemistry, mechanics, and every other branch of science. The knowledge gained by investigation always has formed, and always will form, the only firm foundation on which to build up invention and all the arts of civilization. But it is folly to speak of one class of men as greater than the other; each is equally essential to the complete whole.

Those who wish to help American science must do so by encouraging and stimulating that spirit of patient research which is the very soul of science. We want young men of intelligence who are willing to spend years in the search for knowledge—not merely those who have attained a collegiate degree for learning, but those who have a post-graduate or doctor's degree for research. Research has a reflex educational value to a young man; it is the practical application of his knowledge and talents; it stimulates his intellectual growth, just as the raising of a weight strengthens the muscles.

I.

The outstanding problems in science are difficult, as they have ever been. The very simplest ideas that are commonplace to us cost years of thought before they were first clearly perceived, and centuries of teaching before they were accepted by mankind at large. The atmosphere offers problems so complex that twenty years ago one of the ablest of Englishmen assured me that "they are too difficult to make it worth while for us to attack them at present." Their exact solution must wait until pure mathematics is able to cope with them. In so far as America has even approximately resolved any of these difficulties, she should receive full credit.

The older branch of meteorology, named climatology, considered purely as a study of statistics, began in America about 1817, under the inspiration of Mansfield and Lawton; it was especially fostered by Henry in the Smithsonian, by Lovell as Surgeon-General, by Schott in the Coast Survey, by Watts the Commissioner of Agriculture, and it is now developed by the Weather Bureau. Maury's "Winds and Currents of the Ocean," Coffin's "Winds of the Globe," Schott's "Tables of Temperature and Rainfall," were superior to any similar works published in Europe at corresponding dates. American citizens have also done great work in foreign countries—such, for example, as that of B. A. Gould and W. G. Davis on the climatology of the Argentine Republic. Many colleges and schools teach climatology; Harvard has an admirable school; Johns Hopkins and other universities have excellent courses on this subject.

In the younger branch of dynamic and physical meteorology, our countrymen and our Weather Bureau have been very conspicuous. James Pollard Espy of Philadelphia devoted his life to this subject, and it is impossible to speak of the progress of modern meteorology without mentioning him who is recognized everywhere as its founder. We owe to him the discovery and demonstration of the part played by the latent heat of aqueous vapor in affecting the temperature and motions of the atmosphere. He was able to show that radiation and conduction, which had hitherto alone been thought of, were insignificant factors as compared with mechanical cooling—that is, the consumption by expanding air of its own internal heat when it has to do external work. This principle was demonstrated experimentally by Espy long before our modern thermodynamics was thought of. His writings on this subject, his experiments with his two forms of nepheloscope and his public addresses, both in this country and Europe, were so convincing that they form the starting-point for the study of the thermodynamics of the atmosphere. Although Thomson and Joule greatly developed thermodynamics, mathematically and experimentally, its bearing on meteorology was neglected by Europeans until about 1874, when Julius Hann wrote: "We must return to Espy and Ferrel." Since that date, Germans have done much, but they have not surpassed the work done by recent American meteorologists.

To Espy we owe the invention of the whirled or sling psychrometer, and a method of determining the moisture in the air which is now recognized as the only competitor of the ventilated psychrometer, recently improved by Assmann.

Espy's study of the ascending and descending currents of air led him to the true explanation of the formation of warm foehn winds, cumulus clouds, thunderstorms and tornadoes, and the regular recurrence of strong winds in the daytime and feeble winds at night. It is a significant proof of European ignorance of America, that Espy's conclusions on the latter subject were independently deduced thirty years later by Koeppen, so that Germans are now willing to speak of the Espy-Koeppen explanation, although, according to the established rules of ethics, the credit belongs to Espy alone.

Closely connected with Espy's theory of the formation of clouds, is the work done by Carl Barus at Washington and Providence on the phenomena of cloudy condensation. If he is allowed to prosecute his work further, he will eventually tell us how rain and lightning are formed.

The winds and storms of the atmosphere can be best studied by the use of graphic charts, showing what is going on over wide regions, both at the surface of the earth and above it. In this branch of study Espy was indefatigable, and his popular nickname "The Storm King" was well deserved. Beginning with local thunder-storms in Pennsylvania, he organized, in 1831, a special committee of the Franklin Institute, and in 1836 a joint committee of the Institute and the American Philosophical Society. He secured hundreds of observers, and compiled many storm maps as the basis of his work "On the Philosophy of Storms." In 1842, he came to Washington as meteorologist to the Government, and was assigned to duty, first under the Surgeon-General of the Army, afterwards under the Secretary of the Navy, but eventually, after 1848, under Professor Joseph Henry. In these positions he compiled a continuous series of daily weather maps of the United States, many of which were published in his four successive reports. He established numerous generalizations relating to the storms and some rules by which weather predictions could be made and were made. As Europe boasts of Cuvier, Agassiz and Humboldt as the founders of comparative anatomy, biology and climatology, so must America claim Espy, Redfield, Loomis and Ferrel as founders of the comparative study of daily weather conditions.

William C. Redfield studied the mechanism of storms on the ocean, as Espy did those on land. From the hurricane of September 3, 1821, onward, numerous great storms on the Atlantic and Pacific were examined by him. Redfield's work consisted in most diligently collecting and charting marine reports; and his deductions gave us the first fairly correct insight into the mechanism of a hurricane. This was an advance in marine meteorology superior to anything that had occurred up to his time, and assured us that storms in all parts of the world were analogous and were controlled by a few simple laws.

The study of the atmosphere on a grand scale has been the special field of American meteorologists. The beginnings made by Espy and Redfield were developed by the Smithsonian Institution so as to cover the whole continent, and by Maury so as to cover all oceans. Eventually, in 1873, General A. J. Myer, as Chief Signal Officer of the Army, was able to organize a general international, simultaneous service for the globe, and for many years he published a daily weather map of the whole Northern Hemisphere. For the first time in the history of the world, this international bulletin and map made possible the study of the atmosphere on a proper scale.

America has a pre-eminent right to the glory reflected by the name of William Ferrel, whose innate genius, developed by persistent study under most adverse circumstances, enabled him to do for dynamic meteorology what Espy did for the physics of the atmosphere. The publication, in 1856, of Ferrel's short popular paper on winds and currents, and, in 1858-60, of his mathematical paper on the motions of fluids and solids on the surface of the rotating earth, is, we believe, everywhere recognized as the starting-point of modern dynamic meteorology. Of course, his papers, which were published in journals unknown in Europe, suffered the neglect usually experienced by utterances which are too far ahead of the time. Although a few separate prints of his memoir of 1860 were sent both by Ferrel and myself to European students, and although Ferrel's work was the basis of my "Probabilities" in Cincinnati and Washington, he was not recognized in Europe until 1875, when, for the benefit of the readers of the "Journal of the Austrian Meteorological Society" Professor Hann gave an appreciative review of one feature of Ferrel's work, namely, the demonstration that every movement of the atmosphere is accompanied by a deflection to the right in the Northern Hemisphere, by reason of the daily rotation of the earth on its axis.

Ferrel's explanation of the cause of the rotation of storms; his general theory of atmospheric circulation; his explanation of the origin of the low pressures in the Arctic and Antarctic zones and in the Equatorial belt, and of the high pressures under the Tropics; his determination of the frictional resistances of the land and water to the wind; his explanations of the phenomena of waterspouts, tornadoes, hail, monsoons and other matters too numerous to mention, are all to-day accepted with various modifications due to the recent progress of mathematics and physics. Ferrel placed the mechanics of the atmosphere on the right foundation, removing errors entertained by Europeans who had not properly studied the laws of fluid motion. More elegant mathematical solutions of some of his problems have been given by later European students, and the best general view of the subject has lately been published by Professor Bigelow, of the United States Weather Bureau, so that American science still remains at the head, so far as concerns this branch of meteorology.

Ferrel also knew how to make practical applications of his knowledge. We have from him the best explanation of the action of the sling psychrometer, and tables for computing atmospheric moisture; a system of reduction of barometric pressure to sea level; the proper method of using the bright and black bulb thermometers *in vacuo,* and many other improvements bearing on astronomy, meteorology and mathematics. His machine for predicting the tides is still used in the United States Coast and Geodetic Survey as a labor-saving contrivance. He was the first to demonstrate the influence of tidal friction in retarding the rotation of the earth on its axis.

At the present time, there are among meteorologists in America two men whose names are as well known in Europe as here—namely, Professor Marvin, skilful in the laboratory, and Professor Bigelow, accomplished in mathematical analysis. The same may be said of the meteorologists at the Blue Hill Observatory, where special attention has been given by Messrs. Rotch and Clayton to the study of the upper air. American work is worthy of the highest praise and has stimulated similar work in Europe. As regards organization and practical results, the United States Weather Bureau, under Professor Willis L. Moore, is doing the greatest and best work that has ever been done in any applied science; in its way, this Bureau is equal to the Pasteur Institute or anything else that Europe has to show. No European would deny that, in this respect, America is easily the first in the world.

II.

After all, however, it is less important to defend American science from criticism than to seek out methods by which future progress may be stimulated. I do not expect great benefits from large central institutes, clubs or societies; the present desideratum is the production of a large number of able investigators. So far as research is concerned, I think its best interests would be conserved by encouraging young men to attain the degree of Ph.D. by doing at least one good piece of original investigation. When we have thousands of such young men, we shall easily find the men of promise through whom science will be advanced.

A collegiate education in the ordinary sense of the word does not make men of research, but men of learning. The degrees of A.B., A.M., B.S., M.D., C.E., etc., are given for excellent knowledge of the subject only. College courses and laboratory practice teach the youth what has been done; they prepare him to begin original work for the increase of knowledge. When it comes to this point in their courses of education, however, many excellent students display a certain sluggishness, or, as Tyndall would say, "a lack of the scientific imagination." Our problem is to stimulate and cultivate the intense mental energy needed by the investigator. Those who have a special genius for research are so desirable as leaders for younger men that a first-class university does not hesitate to seek them out and attach them to itself. A beautiful illustration of this fact is found in the following quotation from the report of President Eliot, of Harvard, for the year ending September 26th, 1901:

> "Last summer, the Prussian Government offered our Assistant Professor, Theodore W. Richards, a full professorship of chemistry in the University of Göttingen, and described the professorship 'as offering ample opportunities for chemical research.' . . . . The desire of the Corporation to retain the services of Professor Richards caused that body to consider the conditions under which it was reasonable to expect professors engaged in instruction to be also successful original investigators. To determine the just relation between instruction and research is one of the most difficult of modern university problems . . . . To provide a laboratory, or a library, or a salary derived from endowments, is not the whole of proper university action aimed at the production of competent investigators. The university service for such men must be wisely planned, and those plans must be executed with far-seeing skill. The endowment of research is becoming an attractive object for private benevolence, but the world has little experience of wise schemes for this purpose. The Corporation endeavored to make with Professor Richards an arrangement of his work which will leave him a teacher, and yet give him time and facilities for chemical research and for creating a school of chemical investigators . . . . It is a pleasant feature of this unique negotiation that it holds out a hope that America may before long begin to repay to Germany some of the immense educational benefits which the German universities have conferred on the American."

I am told that Prof. Richards's work in inorganic chemistry, and especially the determination of the atomic weights, had placed him in the front in a field that had once almost wholly belonged to Germany.

Although some American universities thus appoint men of research to their professorships, many appoint their professors under the influence of other ideas. Of course, minor considerations inevitably come into play in the ultimate decision as to the filling of a given vacancy; yet, if the first and major consideration is simply, "What has this man done that demonstrates his intellectual energy, his productiveness, his enthusiasm, his intimate knowledge of the subject, his fitness to lead those who must be taught?" then we shall certainly rule out all undesirable candidates. This principle has been clearly apprehended in Europe, and has been systematically developed to a remarkable extent in Germany. Her prominent position in the scientific world results primarily from this, namely, that her universities have recognized the value of the rule that "the men of the highest and deepest knowledge are shown by their researches, therefore no one shall be appointed *Lehrer* or *Privat Docent* who has not already, in one or more ways, contributed something original and important to the increase of knowledge regarding his special subject; and no one shall retain these humble places, or be advanced to the higher professorships, who does not continue to contribute original works that add still more to our knowledge."

Youths who enter German universities and technical schools see that successful research is properly rewarded, and they shape their lives accordingly. The friends of education in America must not labor exclusively for the diffusion of knowledge and ignore the increase of knowledge. The truths of nature, be they material or spiritual, are worth the great labor that it costs to get at them, and we are well repaid for disseminating them. Whether we study history or philosophy, physical science or religion, politics or sociology, still investigation and research, experimentation, observation and logic will always be in order. These alone can lead to the increase of knowledge. Every candidate for the degree of Ph.D. should know that a brilliant thesis in research will bring him substantial encouragement. Under this stimulus, the German universities have, for the past five generations, been turning the best national thought toward the development of the genius for investigation in every possible field of knowledge. Tens of thousands have received some recognition for research, and ten per cent. of these have become eminent by their discoveries. Not only the university but the whole country profits by scientific progress. Her manufacturers, her ship-builders, her railroad, telegraph and mining engineers, and even her ruling aristocracy, have gone through her universities or technical schools, and are thoroughly imbued with the truth of the principle that "knowledge is wealth, power and pleasure."

We must increase our national activity in this respect. Our universities send forth annually perhaps one-tenth as many young men devoted to research as does Germany. It is a matter that needs no demonstration that there is about an equal proportion of youths of innate intellectual ability in America and in Europe, but these die like the wasted seeds unless circumstances contribute to their proper growth. I look upon the development of a genius among men as the florist looks upon a so-called "sport" among flowers; the latter grows wherever a seed of abnormal proclivities accidentally falls into a favorable soil and develops into a new variety of plant. Such were Copernicus, Tycho Brahe, Galileo, Kepler, Newton and many other famous men. It is the province of our universities to nourish a host of post-graduate research students, in the confident expectation that here and there there will develop a genius that shall be a tower of strength.

As the prospect of congenial employment encourages young men to do good work in hope of recognition, so the endowment of research, and a little assistance from trust funds administered in the interest of research, encourage the older men, and often decide whether a given study shall be undertaken or not. The past history of funds for the endowment of research will, I think, show that applications for assistance, as compared with the actual grants of aid, have been in the ratio of ten to one. The total number of applications, rather than of the grants, indicates the intellectual aspirations of our countrymen. It shows what our men wish to do, but are only able to accomplish when they have financial help. The administrators of these funds sometimes allow them to be expended on apparatus, at other times on incidental expenses, the hire of assistants, office rent, etc.; but they rarely authorize the responsible chief of the investigation to apply the money to his own living expenses. They proceed on the assumption that he has an income from his own fortune or from other daily work, and that the proposed research is a minor undertaking, additional to current duties. This policy results in withholding help from the young scientist, and forces the older ones to be very cautious in applying for help. The most important investigations demand much time, and the student should be free from all other cares and completely devoted to the work in hand. It is certain that science has only received bountiful returns when her investigators have been supported steadily and with generosity, straight through the years of toil that their work required.

The problem of stimulating research is not a new one in the United States. A small percentage of Smithsonian and Hodgkins funds has always been available, and similar smaller funds are in other hands. Several millions have also been invested in institutions intended for research and instruction, such as astronomical observatories, chemical and physical laboratories, geological, zoological and botanical museums or gardens, and scientific libraries. But the endowment of research results in important additions to our knowledge only when the right men are thereby set to work. Undoubtedly, America has several such men.

The law of supply and demand applies to science as well as to commercial matters. If there be no demand for improvement, the improvements and the inventors retire alike into the background, or are altogether eliminated. The Patent Office has been organized to secure the rights of inventors and stimulate that side of our national progress. No analogous organization has as yet been established for the defence of the rights of the original discoverers. We have no national or federal recognition of the general principle that original research, the discovery of new laws or new elements, new stars or new truths of any kind in nature, is of any importance whatever to the individual or to the nation. However, our governmental departments do make appointments on the basis of work done in history, biology or physics, and this policy is bringing about good results.

III.

As regards the future of the science of meteorology, we have to build up from the bottom. I have elsewhere pointed out that our educational institutions have as yet confined themselves to climatology, and offered too little encouragement to the study of the fundamental dynamics. The Weather Bureau has found it necessary to rely entirely upon its own courses of instruction in preparing and promoting its observers and forecasters. Can it be true that the study of this subject is not fully appreciated in America? Such neglect should be remedied by the establishment of schools of meteorology on an equality with other schools of science. Do we need hundreds of astronomical schools and not one meteorological? There may be a hundred young men in the country studying elementary science who are sufficiently interested in meteorology to think of devoting their whole energies to that subject if they but knew of a teacher, and had any assurance that they could earn a livelihood and make a career in this profession. They should not be told that there are no opportunities for them. There should be at least one school of highest character for meteorological research. The admirable papers published by the students of Professor R. S. Woodward, especially those of Cottier, Ling and Davis, on problems of hydrodynamics and the atmosphere, show that under such a master an important school of meteorology would rapidly develop. The works of Mendenhall, Trowbridge, Marvin, Barus and other experimental physicists show what they could do for our science if they were able to devote their whole time to it.

It is not to be denied that, at present, the progress of meteorology in this country depends very largely upon the encouragement given by the United States Weather Bureau to the highest class of scientific research. This Bureau centralizes the entire Government patronage in this respect. There is scarcely an observing station in the country that does not report to it. Its telegraphic organization for reports and daily forecasts reaches every point on the continent. Its forty or fifty sections publish monthly, in great detail, the climatic data of each State and Territory. The whole service is recognized the world over as a model in respect to thoroughness, accuracy and promptness. Moreover, every one is stimulated by its Chief to special study and work under the assurance that his personal ability will be recognized in some agreeable way. The Bureau is a purely Civil Service organization, but that does not mean that it does not need the spirit of progress. It needs to utilize men of research and men of progressive ideas in every branch of its work. Its daily routine of observing and forecasting is not in itself research. The experience of the Weather Bureau is like that of every other organization in the whole long history of science, to the effect that ability and success in research do not result from organization. The gift for research is a style of intellectual energy that refuses to be bound by regulations. An energetic investigator immured in the walls of a great organization may be as much out of place as a wild bird in a cage. He must have intellectual freedom. He can utilize, but must not be dominated by, his surroundings. His mind sees something better than is seen by others, something that is scarcely dreamed of by them. Nature gives him a glimpse of some one of her hidden possibilities, and he has the genius to follow the trail and convert his glimpse into a glorious reality for the rest of us. He studies nature, not policy. It is likely that there are many such men outside, as well as inside, the service. In order to give this latent talent a chance to reveal itself, the Secretary of Agriculture has taken two important steps. As to the outside talent, he has established a corps of student assistants in all the varied branches of his great department. If these student assistants are chosen preferably from among the holders of the university degree of Ph.D., the greatest possible stimulus will be given to post-graduate work in the scientific schools throughout the land. In order to encourage the talent within the Meteorological Service, Secretary Wilson has encouraged Prof. Willis L. Moore to give the broadest development to a modest periodical entitled "The Monthly Weather Review." This opens its columns to all who are teaching, observing or investigating along the lines of Weather Bureau work, and, thereby, does something to stimulate research and progress. As to those employees of the service who have already shown ability in research, but are much encumbered with executive and routine work, we can only hope that times will change for the better, so that they may have opportunity to show what they can do.

In general, the present development of science in America is highly encouraging. Future progress will depend, not so much on the formation of influential scientific clubs as on our laboratories, our periodicals, our local societies and the policy adopted, as to patronage, by the government and our universities. Meteorology will especially advance whenever some one establishes a meteorological laboratory in connection with some first-class university, giving it conveniences for experimentation on a large scale, furnishing it with an experimental physicist, a mathematical physicist, and several student fellowships, and allowing these abundant time to work out completely the first few problems that they may see fit to undertake.

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